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EXPLOSIBILITY OF GASES FROM MINE FIRES

BY

GEORGE A. BURRELL AND GEORGE G. OBERFELL

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EXPLOSIBILITY OF GASES FROM MINE FIRES.

By George A. Burrell and George G. Oberfell.

INTRODUCTION.

This report presents the results of observations of gases produced during mine fires, and the liability of such gases to explode. The first part deals with a fire that resulted in an explosion. Information obtained regarding the gases that caused the explosion allowed some conclusions to be reached regarding the parts played by the combustible gases produced by the fire and regarding the methane that was normally given off by the coal seam. The report is published by the Bureau of Mines in the hope that the information presented will make for greater safety in coal mining.

Only those facts are reported herein that have a distinct bearing on the study of the gases produced during the fire investigated. No attempt is made to describe in detail the fighting of the fire or all of the expedients that were adopted in quenching it.

BRIEF DATA REGARDING MINE FIRE AND EXPLOSION INVESTIGATED.

A mine fire was discovered in a certain drift coal mine early in the afternoon of a working day. The miners were immediately notified and left the mine in safety. Two and one-half hours later a party of 12 men entered the mine to discover the location of the fire. While the men were in the mine the ventilating fan was reversed. About one-half hour after the entrance of the men into the mine an explosion happened, three of the men being severely burned. Seemingly, the explosion happened shortly after the fan had been reversed.

It is believed that the fire started in a cut-through to an old room, probably being due to the accidental lighting of brattice cloth by a miner's lamp.

The cover over the mine varies from 150 to 300 or 400 feet. There were many openings to the surface in the mine, making exclusion of outside air difficult during the quenching of the fire.

Figure 1 shows a plan of the mine, the point where the fire started, the location of one of the fans, and other details of interest.

COLLECTION AND ANALYSIS OF GAS SAMPLES.

No samples of mine gas were collected prior to or before the explosion occurred. The first gas sample, obtained about 24 hours after

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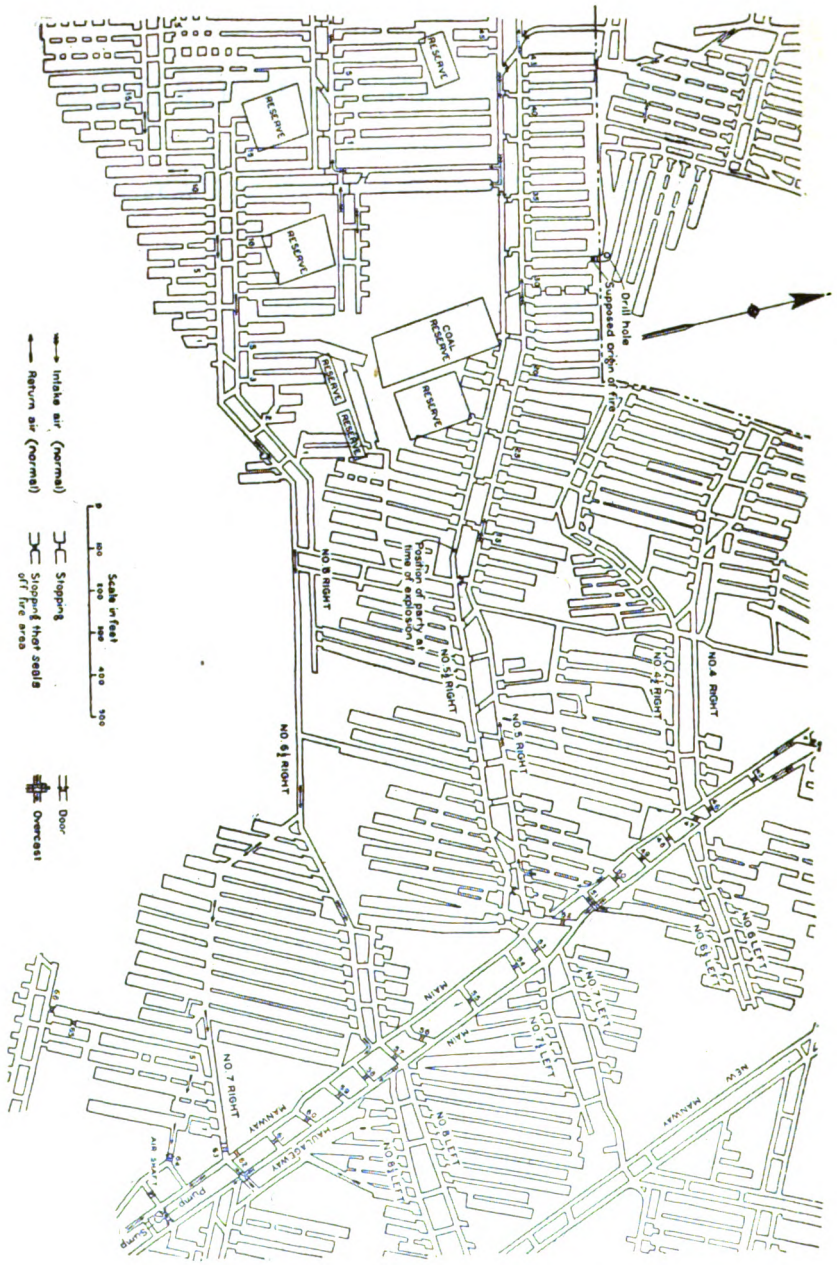

FIGURE 1.—Plan of coal mine in which fire and explosion occurred.

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the explosion, was taken in the return air 20 feet inby the fan. Just prior to the collection of the sample the fan had been started. The results of analysis of the sample (laboratory No. 3369) follows:

Results of analysis of mine-gas sample taken 24 hours after explosion.

[Analyst, G. G. Oberfell.]

	Per cent.
Carbon dioxide (CO_2)	3.00
Oxygen (O_2)	16.51
Carbon monoxide (CO)	.33
Methane (CH_4)	.84
Nitrogen (N_2)	79.32
	100.00

The afterdamp and black damp that had accumulated as a result of the fire and explosion are shown. Another sample (laboratory No. 3371) was collected at the same place 24 hours later or two days following the explosion. The atmosphere was then much better, as the results of analysis given below, show.

Results of analysis of mine-gas sample taken 48 hours after explosion.

[Analyst, G. G. Oberfell.]

	Per cent.
Carbon dioxide (CO_2)	0.55
Oxygen (O_2)	19.77
Carbon monoxide (CO)	.00
Methane (CH_4)	.47
Nitrogen (N_2)	79.21
	100.00

A third sample was collected on the same day, a few feet inby No. 5 right entry. The air was still in there. Brattices had been put in place and much work accomplished in sealing off and confining the fire to as small an area as possible. The results of an analysis of this sample (laboratory No. 3360) follow:

Results of analysis of mine-gas sample taken two days after explosion when some sealing off had been done.

[Analyst, G. G. Oberfell.]

	Per cent.
Carbon dioxide (CO_2)	1.10
Oxygen (O_2)	18.59
Carbon monoxide (CO)	.14
Methane (CH_4)	.41
Nitrogen (N_2)	79.76
	100.00

The foregoing results of analyses are interesting as showing something about the composition of the atmosphere in the mine shortly after the fire had been discovered. No samples were collected in

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or close to the fire because no one could approach it. Hence the results given represent fire gases largely diluted with fresh air from other parts of the mine.

Finally the area wherein the fire was confined was entirely bratticed off as shown in the figure, and the problem resolved itself into waiting until the fire should become quenched through lack of air.

GAS SAMPLES COLLECTED THROUGH BORE HOLE.

A bore hole was sunk at the point shown in the figure. This was completed about 10 days after the explosion and was sunk to procure gas samples from the fire area and to take temperature readings. Pipes were placed in several of the stoppings on the main haulageway and at one of the drift entrances to the sealed area of the mine. From these various openings gas samples were collected at intervals during a period extending over several months. The bore hole pierced the mine workings at a point close to where the fire originated.

The results of analyses of the samples collected from the various openings follow:

Results of analyses of mine-gas samples taken subsequent to an explosion.

[Analyst, G. G. Oberfell.]

Laboratory No.	Source of samples.	Date of sampling.	Results of analysis.				
			CO_2.	O_2.	CO.	CH_4.	N_2.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
3418	Behind No. 40 stopping, at main haulageway.	Mar. 21, 1913[a]	4.8	11.8	0.2	0.8	82.4
3423	.....do.....	.....do[b].....	4.8	11.8	.2	.7	82.5
3454	.....do.....	Mar. 23, 1913	5.4	9.3	.2	1.3	83.8
3455	.....do.....	.....do.....	5.2	9.6	.2	1.3	83.7
3488	.....do.....	Apr. 5, 1913[c]	3.5	12.6	.2	1.0	82.7
3540	.....do.....	.....	3.5	12.5	.2	1.2	82.6
3565	Behind No. 40 stopping...	Apr. 20, 1913	2.2	15.4	.2	.7	81.5
3691	Bore hole.....	May 13, 1913	6.7	5.3	——	3.3	84.7
3712	.....do.....	May 16, 1913	6.4	5.4	——	3.6	84.6
3719	.....do.....	May 19, 1913	6.6	5.2	——	3.5	84.7
3934	.....do.....	June 20, 1913	7.5	6.2	——	2.2	84.1
4111	.....do.....	Sept. 6, 1913	5.3	6.2	——	4.3	84.2
4113	Pit mouth.....	.....do.....	3.7	11.9	——	2.4	82.0
4125	Behind No. 61 stopping...	Sept. 11, 1913	3.0	12.1	——	2.8	82.1
4127	Behind No. 40 stopping...	.....do.....	3.7	11.3	——	2.3	82.7
4131	Behind No. 61 stopping...	Sept. 13 1913	3.4	11.2	——	2.9	82.5
4133	Bore hole.....	.....do.....	5.2	7.1	——	3.8	83.9
4151	.....do.....	Sept. 19, 1913	5.3	6.9	——	4.0	83.8

Less than 0.2.

[a] 2.30 p. m. [b] 3.00 p. m. [c] 9.20 p. m.

On June 7, 1913, an attempt was made to reopen the mine, or at least to determine definitely whether the introduction of fresh air would make conditions worse. Air was forced into the workings. At the same time samples of air were collected at the bore hole and at one of the drift mouths. Samples were taken regularly at both places to observe the change in the mine atmosphere with the introduction of fresh air.

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Results of analyses of mine-gas samples taken subsequent to an explosion and immediately following introduction of fresh air.

[Analyst, G. G. Oberfell.]

[Asterisk (*) following number of sample indicates that sample was taken at drift mouth; other samples taken from bore hole.]

Sample No.	Date of sampling.	Time of sampling.	Results of analysis.				
			CO_2.	O_2.	CO.	CH_4.	N_2.
	1913.	p. m.					
1[a]	May 24	3.20	6.0	4.8		3.6	
2[a]	...do.....	3.20	6.1	4.8		3.4	
1A[b]	June 7	1.00	6.4	5.2		3.6	
2A[b]	...do.....	1.00	6.3	5.0		3.7	
3[c]	...do.....	8.30	6.1	5.3		3.6	
4	...do.....	8.30	5.7	7.7		3.0	
5	...do.....	8.45	5.2	7.2		3.0	
6	...do.....	8.55	5.8	5.8		3.7	
7*	...do.....	9.00	5.3	7.2		3.0	
8	...do.....	9.30	5.9	5.5		3.6	
9*	...do.....	9.45	5.5	6.9		3.0	
10	...do.....	9.55	5.7	5.7		3.6	
11*	...do.....	10.15	5.6	7.2	.2	3.2	
12	...do.....	10.20	6.0	5.7	.3	3.8	
13*	...do.....	10.45	5.3	7.6		3.0	
14*	...do.....	11.15	5.2	7.6		3.0	
15	...do.....	11.20	5.8	6.4		3.6	
16	...do.....	11.45	5.6	6.4		3.8	
		a. m.					
17	June 8	12.15	5.6	6.4		3.6	
18*	...do.....	12.30	5.6	7.2		3.0	
19*	...do.....	1.30	5.2	7.8		2.8	
20	...do.....	1.15	5.2	7.8		3.2	
21*	...do.....	2.30	4.8	8.4		2.8	
22	...do.....	2.15	4.8	10.0		2.8	
23	...do.....	3.15	4.8	10.7		2.6	
24*	...do.....	3.30	4.4	9.3		2.8	
25*	...do.....	4.30	4.6	9.4		2.6	
26	...do.....	4.15	4.2	11.8		2.0	
27	...do.....	5.20	4.4	12.7		2.0	
28*	...do.....	5.30	4.0	10.2		2.4	
29*	...do.....	6.30	4.0	10.9		2.2	
30	...do.....	6.20	4.3	13.6		2.0	

Less than 0.2. — Less than 0.2. — Difference.

[a] Sample taken to determine conditions in the mine if possible; air had not been forced in previous to taking the sample. The mine had been sealed as far as possible for several weeks.
[b] Sample taken about two weeks after samples 1 and 2 had been taken and prior to forcing air into the area. It was believed that the fire had been smothered.
[c] Sample taken after air had been forced into the mine for about 15 minutes.

A sample was also collected in the main haulageway, behind a brick brattice, which had been previously built to seal off the mine. It was taken at 6.20 a. m. June 8, 1913. The results of analysis of the sample follow:

Results of analysis of mine-gas sample taken behind a brick brattice in the main haulageway.

CO_2	3.2
O_2	16.8
CO	.0
CH_4	1.4
N_2	78.6
	100.0

About the time samples 29 and 30 were taken an exploration was made into the mine to determine, if possible, by actual observation the effect the incoming air was having on the fire area. The oxygen

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content by this time had gradually increased until, as shown by the analyses, it had reached about 11 or 13 per cent. It was thought that with this percentage of oxygen present fanning of the fire, if the coal, embers, etc., were sufficiently hot, would take place. Smoke was discovered and evidence obtained that the fire was increasing in intensity. In other words, the reopening of the area had been premature. Consequently the mine-fire area was sealed again.

GASES RESPONSIBLE FOR THE EXPLOSION.

A study of the analyses compels the conclusion that the combustible gases produced by the fire were largely responsible for the explosion. Of the many samples collected in this mine by the bureau's representatives, following the fire, not one contained an explosive proportion of methane. The examination of the gases produced in the mine extended over a period of several months. The highest proportion of methane ever discovered was 4.34 per cent. The sample containing that percentage was collected several months after the fire started. At no time was it possible to get a gas sample directly over the seat of the fire. The samples were collected at other accessible places, and, as far as the combustible gas was concerned, represented that given off normally by the mine. Most of the time, of course, the fan was shut down; hence the methane content represents that which accumulates normally in the mine when air is not introduced to remove it. Only traces of carbon monoxide were found in the sample examined, it is true, but it should be noted that carbon monoxide with any hydrogen or methane formed by the fire would have been produced at the fire—a small place compared with the entire area sealed. Hence the carbon monoxide would have been largely diluted with air from this area, especially at remote points and subsequent to the discovery of the fire.

Regarding the cause of the explosion, the fire had of course been increasing in intensity from the time it had been discovered up to the time the explosion occurred, about 24 hours, subsequently. The fan had been operating all this time, and air was being forced through the fire area—not much probably because the fire occurred near a working face where the air current was still. There was enough, however, so that fresh air was being driven into the area from one side and reacting with coal and probably some wood while the products of combustion were being removed from the other side of the fire area. With the reversal of the fan there was, of course, no sudden and complete reversal of the air current, but a gradual change of the movement of the air. For a short time after the reversal of the fan most of the air would still continue in its original direction. The movement in this direction would diminish, however, until finally all the air would be driven in the opposite direction. Just how long

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a time would be required for the complete reversal in any given mine would be problematical. There would be countless eddies formed as one current met another. The effect on the gases produced by the fire would be a dilution of them with the fresh air and a sweeping back of the mixture into the fire area. The amount swept back would at first be small, but would keep growing larger until a mixture would be obtained that contained an explosive proportion of fire gas. If the temperature at any place in the area were hot enough to ignite this mixture, an explosion would result. This is what probably happened in the case of the fire explosion mentioned.

AIR MOVEMENTS AS FACTORS IN EXPLOSIONS.

Although the sudden reversal of the fan probably precipitated the explosion, yet many explosions following mine fires happen in mines where the ventilation is entirely shut off as far as the fan is concerned. Anything that would cause a movement of the air and thus force explosive gaseous mixtures over a fire area would produce the same result. A fall of rock could sweep gases to a point of ignition. Also, simple diffusion, eddies, and convection currents in a mine where the air was otherwise still could mix explosive gas with air and bring the mixture in contact with flame or with embers hot enough to ignite them.

EXPLOSIBILITY OF GASES THAT MAY BE PRODUCED BY MINE FIRES.

It is interesting to consider the explosibility of those gases that may enter into mine-fire explosions. Those that play a significant rôle are undoubtedly methane, hydrogen, and carbon monoxide. Unsaturated hydrocarbons, such as ethylene, are also produced, but, it is believed, in such small proportions as to be negligible in a consideration of the important gases. The same can be said of ethane. Methane can come from pores and pockets in the coal, at ordinary temperatures, and can be produced by heat reactions. Hydrogen and carbon monoxide are not found normally in coal mines; hence their presence in the gases of mines that are on fire is due to the destructive distillation of the coal or wood, the action of carbon dioxide and hot coal or wood, and the action of steam on hot carbon.

CHARACTERISTICS OF METHANE, HYDROGEN, AND CARBON MONOXIDE.

In explosive characteristics, these three gases, methane, hydrogen, and carbon monoxide, differ considerably. Both hydrogen and carbon monoxide when mixed with air ignite at lower temperatures than does methane, and have much wider explosive ranges, although their lower limits of explosibility are higher than the low limit for methane.

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This is shown in the following table:

High and low explosive limits of three gases.[a]

Gas.	Low limit.[a]	High limit.[a]	Ignition temperature.[b]
	Per cent.	*Per cent.*	*° C.*
Methane	5.5	14.00	650 to 750
Carbon monoxide (moist)	15.00	73.00	651
Hydrogen	10.00	66.00	585

[a] Determined by the authors.
[b] Dixon, H. B., and Coward, F. H., Ignition temperature of gases: Chem. News, vol. 99, 1909, p. 139.

These results mean that when, in a mixture of air and methane, there is present 5.5 to 14 per cent of methane flame will travel entirely through the mixture when it is ignited at one point. Similarly, flame will travel through mixtures of hydrogen or carbon monoxide and air, but the limits are higher. With appreciably less and greater proportions than the percentages given above, pronounced flashes would occur upon ignition, with the development of considerable pressure, but such mixtures could not propagate flame indefinitely.

As far as the low limit is concerned, methane is the most dangerous because a smaller proportion of gas is needed to form an explosive mixture than in mixtures of hydrogen or carbon monoxide and air. Hydrogen and carbon monoxide are more dangerous because their explosive ranges are so much wider.

As regards the combustible gases present in a coal mine, mixtures of all of them in varying proportions are found. In a gaseous mine that normally produces a large amount of methane, the methane would predominate in any part sealed because of a mine fire, for the methane would be accumulating in all parts of the mine, whereas the carbon monoxide and hydrogen would be chiefly concentrated in close proximity to the fire area. In addition some methane could be produced by the fire reactions.

EXPERIMENTS TO DETERMINE EXPLOSIBILITY OF CARBON MONOXIDE, METHANE, AND AIR.

As regards a fire in a nongaseous mine, as in the mine fire described above, only small quantities of methane would accumulate from the coal at ordinary temperatures; the quantities of carbon monoxide and hydrogen would be large or small according to the fire reactions. At any rate, in mine fire investigations one is largely concerned with mixtures of the three gases and air, hence some experiments were made by the author having to do with the explosibility of mixtures of carbon monoxide, methane, and air. The experiments were conducted in a Hempel explosion pipette, a small spark being used as the source of ignition. The results follow.

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Results of experiments to determine explosive limits of mixtures of carbon monoxide, methane, and air.

Mixture.		Low limit.	High limit.
CO.	CH_4.		
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
20	80	6.94	15.89
40	60	7.31	18.26
50	50	8.15	18.66
60	40	9.59	21.18
80	20	10.69	30.17
90	10	12.20	41.45

In further tests having to do with the explosibility of mixtures of methane, carbon monoxide, and air, enough carbon monoxide was added to prepared nonexplosive mixtures of methane and air to make the resultant mixture explosive. The results follow.

Results of experiments to determine inflammability of special mixtures of carbon monoxide, methane, and air.

Methane.	Carbon monoxide.	Effect of spark.	Methane.	Carbon monoxide.	Effect of spark.
Per cent.	*Per cent.*		*Per cent.*	*Per cent.*	
4.25	2.92	No inflammation.	3.11	6.06	No inflammation.
3.92	4.22	Do.	3.18	6.23	Do.
3.94	4.52	Complete inflammation.	2.95	6.47	Complete inflammation.
3.87	4.60	Do.	2.99	6.18	Do.
3.65	4.98	Do.	3.12	6.92	Do.

It will be seen that as the amount of methane is decreased the carbon monoxide must be increased by an amount that brings the total combustible gases to a proportion greater than 5.50, the low limit for methane. This conclusion necessarily follows from the low limits of complete inflammation of the two gases. When about 4 per cent of methane is present there is needed about 4.50 per cent of carbon monoxide to produce an explosion. When about 3 per cent of methane is present there is needed about 6.50 per cent of carbon monoxide to produce an explosion.

The explosive properties of mixtures of hydrogen, methane, and air would be somewhat similar.

PRODUCTION OF COMBUSTIBLE GASES DURING MINE FIRES.

In a fire above ground, combustion may be complete, because sufficient air can be supplied to the burning material to permit the formation of carbon dioxide and water as the principal products of combustion. However, a mine fire is usually quickly covered with fallen coal, slate, timber, etc., and the oxygen content of the mine atmosphere is more or less rapidly diminished, and does not have ready access to the burning fuel. As a consequence, combustion

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soon becomes incomplete, and intermediate products of combustion, such as carbon monoxide, are formed. The character and quantity of the gases produced differ according to the stage of the fire, from the time it is first noticed, through the fighting of it, and up to and through the time it is sealed if sealing becomes necessary.

The changes that take place may be studied by comparing mine-fire combustion processes with changes that coal undergoes and the gases that are given off when the coal is subjected to different combustion processes above ground. Such studies have to do with the destructive distillation of coal in retorts, as in making illuminating gas, the manufacture of coke in coke ovens, the production of producer gas, and the burning of coal in boiler furnaces. Chemical reactions may occur in mine fires that are related to the reactions that take place during any of the above well-known processes, from that of complete combustion, as in properly fired boiler plants, to destructive distillation, as in gas-house retorts, where practically no oxygen enters into reaction except that from the coal.

GASES FROM THE DESTRUCTIVE DISTILLATION OF COAL.

In the destructive distillation of coal the coal is placed in retorts, from which air is almost entirely excluded. The purified and enriched coal gas that is made for domestic use in the city of Pittsburgh may be taken as an example of gas made by the retort process. It has the following composition, according to analyses made by the author:

Composition of gas used by the city of Pittsburgh, Pa.[a]

CO_2	2.33
Illuminants	8.68
O_2	.44
CO	11.38
CH_4	34.99
C_2H_6	1.13
H_2	35.76
N_2	5.29
	100.00

The unpurified gas probably contains about 1.5 per cent of ammonia, hydrogen sulphide, and sulphur dioxide. Oxygen for the formation of CO and CO_2 comes from the coal.

EXPERIMENTS OF BURGESS AND WHEELER.

Burgess and Wheeler[b] found that coal from the Altoft Silkstone seam (England) when destructively distilled evolved gas of the composition noted below. The coal was heated in a retort at a temperature of 450° to 1,100° C.

[a] Analysis made by the authors.

[b] Burgess, M. J., and Wheeler, R. V., The volatile constituents in coal: Jour. Chem. Soc., 1910, vol. 97, pt. 2, pp. 1917–1935.

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Composition of gas evolved from coal from Altoft Silkstone seam.

Constituent	Per cent.
Ammonia, benzene, acetylene, ethylene	14.15 to 4.85
Carbon dioxide	10.95 to 1.70
Carbon monoxide	8.75 to 15.85
Hydrogen	7.00 to 56.65
Methane	25.00 to 17.60
Ethane	34.10 to 3.40

Burgess and Wheeler[a] also heated coal from Abertillery, South Wales, at temperatures ranging from 600° to 1,100° C. They obtained gas of the following composition:

Composition of gas from coal from Abertillery, South Wales.

Constituent.	Per cent.
Ammonia, benzene, acetylene, ethylene	7.75 to 4.30
Carbon dioxide	3.95 to 1.40
Carbon monoxide	4.70 to 13.00
Hydrogen	8.00 to 60.70
Methane	64.50 to 18.80
Ethane	11.05 to 1.80

Coal from Penrhycyber, South Wales, distilled at temperatures ranging from 500° to 1,100° C., yielded gases in the following proportions:[b]

Composition of gas from coal from Penrhycyber, South Wales.

Constituent.	Per cent.
Ammonia, hydrogen sulphide, benzene, acetylene, ethylene	7.55 to 1.15
Carbon dioxide	6.85 to .20
Carbon monoxide	4.60 to 11.10
Hydrogen	15.70 to 72.90
Methane	51.50 to 12.85
Ethane	13.70 to 1.80

DISCUSSION OF RESULTS OBTAINED BY BURGESS AND WHEELER.

As far as these results concern the present investigation the salient details are as follows: With rise in temperature, the carbon monoxide increases from about 4.60 to 8.75, the methane decreases from 64.50 to 12.85, the hydrogen increases from 7.0 to 72.90, the carbon dioxide decreases from 10.95 to 0.20, and the so-called illuminants decrease from about 14.15 to 1.00.

It will be observed that at the lower temperatures carbon monoxide and hydrogen may be produced in proportions nearly alike and in large and explosive proportions but that the tendency is for the carbon monoxide to be subordinate to the hydrogen. At high temperatures this tendency is still more noticeable. In mine fires when

[a] Burgess, M. J., and Wheeler, R. V., Op. cit., pp. 1917–1935.
[b] Burgess, M. J., and Wheeler, R. V., Loc. cit.

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conditions have reached the point where an explosion might occur, that is, after the fire has burned for some time, temperatures will probably have reached their maximum and have started to fall, owing principally to lowering of the oxygen content, and to incombustible material, such as slate from the roof, falling on the fire. Hence the products of combustion that distill at low temperatures may also be of importance. However, when the fire has once reached a high temperature it may cool slowly for usually it will be well insulated. While the fire is cooling products of combustion from the previous high temperature will still be present.

As regards low-temperature distillation, the results of the distillations presented above show that the carbon monoxide evolved did not reach the explosive proportion; the proportions that Burgess and Wheeler found were 4.70 to 8.75 per cent.[a] The low limit of complete inflammation for carbon monoxide in air is close to 15 per cent. As regards hydrogen, Burgess and Wheeler's results show that in destructive distillations at low temperature enough of this constituent may be present to form an explosive proportion. In one case they found a proportion of 15.70 per cent. It must be considered, however, that these products of combustion were produced in the absence of air. Hence a strictly analogous process could not take place in a mine-fire area because air would not be entirely excluded. With an accidental inrush of air, the percentage of inflammable constituents would be lowered below an explosive proportion. Therefore, it can be stated that if the destructive-distillation processes at low temperature within a mine were analogous to the experiments conducted by Burgess and Wheeler on a laboratory scale, an explosion due to the formation of hydrogen and carbon monoxide would not be as likely to happen as in high-temperature distillation.

With methane the case is different. At temperature of 500° C. Burgess and Wheeler found 51.50 per cent in the evolved gases.[a] This followed of course complete exclusion of air, a condition difficult to obtain in the early stages of a mine fire. But if air were excluded and the temperature rose to 500° C. there could be produced enough methane so that even with a large subsequent dilution by air an explosive mixture could result.

EXPERIMENTS OF PORTER AND OVITZ.

Porter and Ovitz[b] distilled a coal from Ziegler, Ill., at temperatures ranging from 390° to 1026° C. and obtained gas of the following composition:

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[a] Burgess, M. J., and Wheeler, R. V., Loc. cit.

[b] Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bull. 1, Bureau of Mines, 1910, pp. 47–48.

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Composition of gas from coal from Ziegler, Ill.

Constituent.	Per cent.
Carbon dioxide	7.5 to 1.6
Illuminants	2.0 to 3.5
Oxygen	1.8 to .3
Carbon monoxide	4.8 to 14.0
Paraffin hydrocarbons	11.3 to 16.9
Hydrogen	.0 to 51.2
Nitrogen	72.6 to 12.5

A coal from Connellsville, Pa., gave the following results with distillation temperatures of 390° to 1008° C.:

Composition of gas from coal from Connellsville, Pa.

Constituent.	Per cent.
Carbon dioxide	3.8 to 1.0
Illuminants	1.8 to 4.6
Oxygen	3.1 to .3
Carbon monoxide	1.8 to 6.6
Paraffin hydrocarbons	9.5 to 23.9
Hydrogen	.0 to 54.8
Nitrogen	8.0 to 8.8

Pocohontas coal gave the following results at temperatures of 612° to 920° C.:

Composition of gas from Pocohontas coal.

Constituent.	Per cent.
Carbon dioxide	1.0 to 0.4
Illuminants	2.8 to 3.4
Oxygen	.4 to .4
Carbon monoxide	4.2 to 4.2
Paraffin hydrocarbons	45.0 to 24.5
Hydrogen	27.5 to 59.0
Nitrogen	19.1 to 8.1

These analyses show that with rise in temperature the carbon dioxide decreases from 7.5 to 0.4 per cent, the carbon monoxide increases from 1.8 to 14 per cent, the paraffin hydrocarbons range from 9.5 to 24.5 per cent, and the hydrogen increases from 0 to 59 per cent. These changes agree essentially with the results obtained by Burgess and Wheeler. Porter and Ovitz did not make a separation of the paraffin hydrocarbons into methane and ethane.

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RESULTS OBTAINED BY PARR AND OLIN.

Parr and Olin[a] show the average results obtained from coal distilled at an average temperature of 400° C., as follows:

Results of analysis of gas from coal distilled at 400° C.

Constituent.	Per cent.
H_2S	3.2
CO_2	5.7
Illuminants	8.3
CO	5.2
H_2	5.0
C_2H_6	14.4
CH_4	51.4
N_2	5.7

EXPERIMENTS OF PARR AND FRANCIS.

Parr and Francis[b] heated Carterville, Ill., coal in a retort in an atmosphere of nitrogen, and collected and analyzed the gases given off. The following table shows the results of their experiments. The analytical results represent averages of analyses of samples collected at different periods of distillation.

Results of distillation of coal in an atmosphere of nitrogen.

Item.	Test No.		
	6	7	8
Temperature, °C	339	369	381
Period of observation, hours	6	3	6
Carbon dioxide and hydrogen sulphide, per cent	21.85	17.33	12.58
Illuminants, per cent	8.67	9.54	10.48
Oxygen, per cent	0	0	.0
Carbon monoxide, per cent	8.42	7.66	6.96
Methane, per cent	2.52	32.66	28.07
Hydrogen, per cent	1.99	2.37	2.07
Nitrogen, per cent	56.44	29.97	39.50
Volume of gas evolved, liters	47	50	45

Parr and Francis[c] also distilled the same coal in a retort in an atmosphere of oxygen.

The composition of the gas evolved, obtained by averaging analyses of samples collected at different periods during the distillation, is shown as follows:

[a] Parr, S. W., and Olin, H. L., The coking of coal at low temperatures: Univ. of Ill. Eng. Exp. Station Bull. 60, 1912, p. 9.

[b] Parr, S. W., and Francis, C. K., The modification of Illinois coal by low-temperature distillation: Univ. of Ill. Eng. Exp. Station Bull. 24, 1908, p. 24.

[c] Parr, S. W., and Francis, C. K., Op. cit., p. 29.

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Results of distillation of coal in an atmosphere of oxygen.

Item.	Test No.			
	1	2	3	4
Average temperature, °C	279	346	379	375
Period of observation, hours	4	4	4½	3
Carbon dioxide and hydrogen sulphide, per cent	5.25	20.80	12.73	13.84
Illuminants, per cent	.00	2.50	3.53	4.24
Oxygen, per cent	13.80	10.40	9.27	7.68
Carbon monoxide, per cent	2.50	6.60	4.74	6.64
Methane, per cent	7.20	12.27	13.68	15.16
Hydrogen, per cent	.00	.00	.00	.00
Nitrogen, per cent	71.25	47.43	56.05	52.44
Volume of gas evolved, liters	12	23	50	45

RESULTS OBTAINED BY WHITE AND BARKER.

White and Barker [a] subjected 17 coals from 10 States to destructive distillation at temperatures ranging from 1,140° to 1,820° F. (588° to 994° C.), and obtained the following results:

Results of analyses of gases evolved by destructive distillation of 17 coals from 10 States.

Constituent.	Per cent.
Carbon dioxide	1.1 to 7.6
Illuminants	3.0 to 6.1
Oxygen	.2 to 1.1
Carbon monoxide	4.9 to 14.4
Methane	29.0 to 37.9
Hydrogen	40.2 to 55.8
Nitrogen	1.8 to 6.6

RESULTS OBTAINED BY OTHER INVESTIGATORS.

Experiments have been performed by other investigators that show the character of the gases given off when coal is destructively distilled, but enough results have been presented to permit general conclusions to be drawn regarding the nature of the gases evolved. It follows that, if gases produced by destructive distillation play an important part in explosions following mine fires, the part played by the carbon monoxide is much subordinate to the part played by hydrogen and the paraffin hydrocarbons, of which methane is the predominant constituent. At the higher temperatures the carbon monoxide would be contributory but much subordinate to the paraffins and the hydrogen. At temperatures close to the beginning temperature of distillation the methane formed should be the most important gas, and hydrogen and carbon monoxide about equally contributory.

[a] White, A. H., and Barker, Perry, Coals available for the manufacture of illuminating gas: Bull. 6, Bureau of Mines, 1911, p. 46.

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GASES FROM THE DESTRUCTIVE DISTILLATION OF WOOD.

The purified gases produced by the destructive distillation of wood contain a large percentage of carbon dioxide—up to 60 per cent—carbon monoxide up to 35 per cent, heavy hydrocarbons up to 10 per cent, and much smaller quantities of methane and hydrogen than are produced from coal. The destructive distillation of coal and timber produces also benzol, creosote, and acetic acid. The latter two contribute to the characteristic odor that becomes perceptible before smoke is noticed and lingers in a mine long after the fire is out and smoke has disappeared. Wood begins to distill at a lower temperature than coal, probably about 250° or 280° C. The formation of carbon monoxide begins at a lower temperature with wood than with coal.

GASES EVOLVED IN THE GAS PRODUCER.

Temperatures in the gas producer may be considerably higher than those in a coal retort in which destructive distillation is taking place. Air is introduced into the producer, and coal oxidizes as well as distills. The distilled gases come in direct contact with incandescent carbon, and several processes take place, as follows:

1. The distillation of volatile hydrocarbons from the freshly fired fuel, at relatively low temperatures.

2. The combustion of the fuel by its combining with the oxygen of the air, forming carbon dioxide.

3 The formation of carbon monoxide and hydrogen, the essential constituents of producer gas, in accordance with the equations:

$$CO_2+C=2CO$$
$$H_2O+C=CO+H_2$$

The formation of the carbon monoxide depends upon the temperature, the depth of the hot parts of the fuel, and the rate of flow of gas through the bed. Clement and Adams[a] found that at temperatures of 1,300° C. and zero velocity practically all of the carbon dioxide in contact with incandescent carbon (coke) is converted into carbon monoxide. When the time of contact was 1 second they found that 80 per cent of the carbon dioxide was converted into carbon monoxide. At 600° C. and zero time of contact they found that 10 per cent of the carbon dioxide was converted into carbon monoxide.

Clement and Adams also showed the variation in the amount of carbon monoxide at the various temperatures. The air was converted quantitatively to carbon dioxide. The maximum amount of carbon monoxide formed when air is used can not exceed 33 per cent.

[a] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas: Bull. 7, Bureau of Mines, 1911, p. 16.

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They found that at a temperature of 600° C. 8 per cent of carbon monoxide was formed when the velocity of the carbon dioxide over the coke was zero. This value was not determined experimentally, but was extrapolated from determined points. Under the same conditions but at 1,000° C. they found that about 32 per cent of carbon monoxide was formed. On the other hand, when the carbon dioxide was passed over the coke at the rate of 0.5 foot per second only about 1 per cent of carbon monoxide was found at 900° C.

Other constituents in producer gas are carbon dioxide, hydrogen, nitrogen, and small quantities of methane. As far as mine fires are concerned, methane, which may be formed through reactions similar to those that occur in gas producers, may be neglected as insignificant. The hydrogen formed is always less than the carbon monoxide. Much producer gas made on a commercial scale has approximately the following composition:

Composition of typical producer gas.

CO_2	6
CO	25
H_2	12
CH_4	1
N_2	56

It follows that if combustion reactions during mine fires are similar to those that take place in the gas producer, carbon monoxide can be produced in quantity sufficient to form with air an explosive mixture.

GASES FROM COMBUSTION PROCESSES IN BOILER FURNACE.

In boiler furnaces attempt is made to obtain complete combustion and a large excess of air is admitted to the fuel bed. The products of combustion are almost entirely CO_2, H_2O, and O_2. Sometimes small amounts of CO and traces of methane and hydrogen are formed, but effort is made to avoid their formation. The formation of CO in the boiler furnace is favored by a heavy fuel bed. The greater the supply of air to a given depth of bed the less should be the percentage of CO formed. In order to burn CO produced in a boiler furnace it is necessary that sufficient air be added to the hot gases as they leave the top of the fuel bed.

Porter and Ovitz [a] quote Constam and Schläpfer as finding in the waste gases from boiler furnaces 3.5 per cent of carbon monoxide and 1.5 per cent of hydrogen. Such percentages of unburned gases are of course exceptional where effort is made to obtain high efficiency in boiler-furnace operation. Porter and Ovitz [b] also quote from the

[a] Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bull. 1, Bureau of Mines, 1910, p. 8.
[b] Porter, H. C., and Ovitz, F. K., Op. cit., p. 7.

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Manchester (England) Smoke Committee some flue-gas analyses showing in certain tests of hand-fired furnaces 0.25 to 0.40 per cent of methane and 0 to 1.0 per cent of hydrogen. The same authors state that in tests made at the Bureau of Mines experiment station in Pittsburgh, Pa., the flue gases contained as high as 2.8 per cent of carbon monoxide and nearly 1.0 per cent each of hydrogen and methane. The author of this report has found as much as 1.00 per cent total methane, carbon monoxide, and hydrogen in flue gases from a boiler furnace that was purposely fired in an uneconomical manner.

When coal burns on the grate of a boiler furnace the combustible part that is distilled consists principally of carbon monoxide, hydrogen, and methane. In addition minute tar globules and tiny pieces of solid carbon and even small pieces of coal are given off. In the 2 or 3 inches next the grate the carbon burns to CO_2, which is decomposed to CO as it passes through the upper layers of hot coal. The temperature above the fuel bed should be high enough and the air supply sufficient to burn these combustibles. If the temperature is not high enough and the combustion space not large enough, they are rapidly carried to a cool part of the furnace where they are cooled below their ignition temperatures. Similarly if the air (oxygen) supply is insufficient they escape unburned.

It can be readily perceived that in a mine fire part of the combustible gases produced might remain unburned because they have opportunity to cool below their ignition temperatures before coming in contact with oxygen.

PRODUCTION OF WATER GAS.

Formation of any appreciable quantity of water gas during a mine fire is probably rare. Water gas is produced when incandescent carbon combines with water vapor, forming hydrogen, carbon monoxide, and carbon dioxide. The principal reactions are represented by the following equations:

$$H_2O + C = CO + H_2$$
$$2H_2O + C = CO_2 + 2H_2$$
$$H_2O + CO_2 = H_2O + CO$$

The composition of the gas obtained when a stream of superheated steam is passed through a bed of glowing carbon, as well as the quantity of steam decomposed in a given time, vary with the temperature, the rate of flow of the gas, and the kind of carbon used. At a temperature of 800° C. and with time of contact of 1.019 seconds, Clement and Adams[a] found that gas of the following composition was produced when steam was passed over hot coke:

[a] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas. Bull. 7, Bureau of Mines, 1911, p. 41.

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Composition of gas formed by passing steam over hot coke, temperature 800° C.

Constituent.	Per cent (dry gas).
CO_2	4.8
CO	34.4
H_2	42.5

Under the same conditions but at a temperature of 1,300° C. gas of the following composition was produced:

Composition of gas formed by passing steam over hot coke, temperature 1,300° C.

Constituent.	Per cent (dry gas).
CO_2	0.3
CO	49.5
H_2	45.8
CH_4	1.9

Clement and Adams [b] quote from report of results of tests by Harries, who passed water vapor over charcoal and produced gas of the following composition:

Composition of gas formed by passing water vapor over hot charcoal.

Temperature.	Gas evolution per second.	Analysis of gas.				
		H_2.	CO.	CO_2.	H_2O.	H.
°C.	Liters.					
674	.9	8.41	0.63	3.84	87.12	.....
758	1.8	22.28	2.67	9.23	65.82	.....
838	3.28	32.77	7.96	12.11	47.15	.....

When water is thrown on red-hot coals some water gas is formed. But the water immediately has a cooling effect, and where it strikes the fuel the temperature is rapidly lowered to a point at which the water-gas reactions can not take place. The writers have no experimental evidence of the quantity of gas that might be produced, but feel certain that not enough could be formed to be of significance in producing an explosive atmosphere, or adding inflammable material to an atmosphere that might be already nearly explosive.

GASES RESPONSIBLE FOR MINE-FIRE EXPLOSION PREVIOUSLY DESCRIBED.

A review of the facts obtained in the study of the mine-fire explosion mentioned in the first part of this report and of the discussion of mine-fire gases clearly shows that carbon monoxide was in part responsible for the explosion. Appreciable proportions of the gas was found in different parts of the mine after the fire gases had been largely diluted with air. Hydrogen was not detected in appreciable

[b] Clement, J. K., Adams, L. H., and Haskins, C. N., Op. cit., p. 52.

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quantities. However, it was undoubtedly formed at the fire, but in quantities less than the carbon monoxide.

The proportion of methane did not rise at any time to a point indicating with certainty that large quantities were being produced by the fire. Methane was given off by the coal itself long after the fire was extinguished. However, the evidence is not convincing because no samples of gas were collected over the area of the fire during its hottest stages and those fire gases that were collected were largely diluted with air from other parts of the mine. A highly explosive mixture of combustible gases and air could have formed near the fire at its hottest stage and later when it was cooled the mixture could have been so greatly diluted with air, especially at points removed from the fire, that the combustible gases would be present in small proportion.

Carbon monoxide is produced by destructive distillation, although in small proportions as compared to the methane and hydrogen. In much larger proportions it could be produced by the reduction of carbon dioxide by means of hot carbon, like the reaction in the gas producer, and this reaction was probably mainly responsible for the carbon monoxide produced.

Methane from the coal seam also undoubtedly assisted in the explosion, but methane from this source could not have been wholly responsible because, as shown by many analyses, it does not rise to the explosive proportion. It seems that the two gases, carbon monoxide and methane, assisted by smaller amounts of hydrogen, were chiefly responsible. Part of the methane was produced by the fire.

CHARACTER OF GAS SAMPLES OBTAINED FROM OTHER MINE-FIRE AREAS.

SAMPLES FROM FIRE AREA OF ANTHRACITE MINE.

Gas samples were obtained by the authors of this report from behind one of several dams that sealed a fire area in an anthracite mine. The dam was situated about 30 feet from the fire area. At the time the samples were collected air was slowly leaking through another dam and some of the products of combustion were reaching the point of sampling. As some of these products of combustion were leaking out through the dam, compressed air was used to make the atmosphere outside the dam respirable while the samples were being taken. The results of analyses of the samples follow:

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Results of analyses of gas samples from a fire area in an anthracite mine.[a]

Sample No.	Date of sampling.	Time of sampling.	Constituents in sample.				
			CO_2.	O_2.	CO.	CH_4.	N_2.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Oct. 27, 1910	5 p. m.	3.5	8.3	1.3	11.5	75.4
2	do	12 p. m.	3.8	9.6	.7	13.1	72.8
3	Oct. 28, 1910	9.45 p. m.	3.4	10.9	.6	10.8	74.3
4	do	4 p. m.	3.4	11.3	.6	10.3	74.4
5	do	4.30 p. m.	3.0	12.6	.4	9.6	74.4
6	Oct. 29, 1910	11 a. m.	3.3	14.1	.6	9.0	73.0
7	do	3.30 p. m.	4.1	13.6	.8	12.0	69.5
8	Oct. 30, 1910	10.30 a. m.	4.8	10.1	1.2	14.1	69.8
9	do	5 p. m.	4.0	12.2	1.0	12.2	70.6
10	Oct. 31, 1910	6.30 a. m.	12.2	6.6	.4	6.6	74.2

[a] In all of the gas samples the proportion of hydrogen was less than 0.20 per cent.

When sample 1 of the foregoing series was taken the fire was seemingly under control. Air commenced to leak into the area, however, when the air current was forced through a near-by gangway while effort was being made to free a remote part of the mine from accumulated fire damp, black damp, etc., and in consequence, as shown by analysis, the oxygen in the atmosphere of the fire area increased. Simultaneously the carbon dioxide, carbon monoxide, and methane commenced to decrease as the accumulated products of combustion of the fire were diluted by the incoming air. The progressive change reached its maximum when sample 6 was taken. At this time the fire burst forth with increased intensity. The oxygen then dropped and carbon monoxide began to form in increased quantities. Efforts to tighten the stoppings inclosing the fire area were then commenced, but before these were made completely tight the air content of the area again increased, as is shown by the results of analysis of sample 9. Finally, efforts at tightening the brattices were successful. The large proportion of carbon dioxide in sample 10 was due to the fact that carbon dioxide from a fire extinguisher had been forced into the area just before the sample was taken.

In trying to determine from these analyses the composition of the atmosphere at the fire, one meets with difficulty because the products of combustion from the fire were diluted with air from other parts of the sealed inclosure, and, with methane given off from the coal, the methane would accumulate in an inclosed area whether fire was present or not. The analyses are accurate to about 0.20 per cent. Hydrogen, although undoubtedly present, did not exist in proportions greater than 0.20 per cent. The oxygen diminution was undoubtedly principally due to absorption of same by the coal not on fire. Carbon dioxide in small proportions would have resulted from the action of oxygen on the coal at ordinary temperatures. It must be remembered, of course, that there was no fire in

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a large part of the inclosed area, in which the temperature was probably not much higher than normal.

The methane stands out as the explosive gas, and its presence is explained by the fact that it is normally given off in some mines. The carbon monoxide was probably principally produced in the same manner that it is formed in boiler furnaces when combustion becomes incomplete. In this case that it could have added materially to the methane in causing an explosive atmosphere may be assumed because as much as 1.2 per cent was detected next to the stopping at a point 100 feet from the fire. It must be borne in mind, however, that at the fire (where the carbon monoxide was present in larger proportions and undoubtedly some hydrogen also present, although in smaller proportion than the carbon monoxide) the oxygen was also much lower than at the point of sampling, and a considerable dilution with air would have been necessary to produce an explosive mixture. Even at the point of sampling the atmosphere was explosive probably at only part of the fire-fighting stage—when samples 6 and 7 were taken. Experiments by the bureau's investigators have shown that when the oxygen in a mixture diminishes to about 13.5 per cent an explosion can not occur.[a] With inrush of air to the seat of the fire in this particular case the products of combustion from the fire would be diluted to a large extent, hence the proportion of carbon monoxide (or hydrogen) would have to be large if, after dilution with air, enough were to be left to be of much significance in producing an explosive mixture. As regards methane, the proportion present at the seat of the fire was probably only little greater than that at the point of sampling behind the dam, for, as already stated, the methane present represented principally an accumulation of methane normally given off by the coal, and this accumulation should not have been greater in one part of an inclosed area of a mine than in another part.

No explosion occurred during the fighting of this fire, probably because, as the methane and products of combustion accumulated at the seat of the fire, the oxygen diminished to a point so low that an explosion could not have taken place even if, after the smothering action due to low oxygen and falls of roof and débris, enough heat had still remained to cause an ignition of any explosive mixture that might have been present.

SAMPLES FROM FIRE AREA OF MINE WORKING PITTSBURGH BED.

Samples of gas were collected from behind stoppings that were built to seal off a fire close to the mouth of a drift mine working the Pittsburgh bed. The first sample was taken through a hole in a con-

[a] Clement, J. K., The influence of inert gases on inflammable gaseous mixtures: Tech. Paper 43, Bureau of Mines, 1913, 24 pp.

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crete stopping, near the fire, one day after the mine had been sealed. The second and third samples were collected at the same place. Shortly after the third sample had been taken water that had been forced in rose so high inside the dam that more samples could not be collected.

Results of analyses of gas samples from the sealed area of a burning mine.

Sample No.	Date of sampling.	Time of sampling.	Constituents in gas.					
			CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.
	1910.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	June 10	7.30 a. m.	9.14	1.83	1.32	3.60	1.02	83.09
2	...do....	2.00 p. m.	8.10	2.80	1.61	1.13	.35	86.01
3	June 11	8.00 a. m.	8.03	3.47	1.36	1.10	.35	85.69

The following samples were collected from the same mine by inserting a tube in a small hole driven through the thin roof covering the main heading near the mine mouth. The samples thus collected represent gases from a hot part of the burning section.

Results of analyses of gas samples from hot part of sealed area in a burning mine.

Sample No.	Date of sampling.	Time of sampling.	Constituents in gas.					
			CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.
	1910.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	May 22	7.35 p. m.	6.07	1.69	1.58	3.37	1.37	83.90
2	May 23	1.00 p. m.	8.03	3.13	1.25	1.14	.29	86.16
3	May 24	8.00 a. m.	8.14	3.00	1.41	1.21	.35	85.89

Samples were taken from behind another stopping, which was situated about 2,000 feet away from the burning section, by boring a $\frac{3}{4}$-inch hole in the wooden brattice and drawing the gas into the sample container with a small air pump. Later, investigators wearing breathing apparatus entered the mine at this place and obtained three samples of air at points approximately 200, 600, and 800 feet inward from the stopping. Samples could not be collected farther in than 800 feet because of the heavy pall of smoke encountered. The results of analyses of the samples are as follows:

Results of analyses of gas samples from remote parts of sealed area in a burning mine.

Sample No.	Point of sampling.	Constituents in gas.					
		CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Through stopping	3.47	13.65	0.60	1.01	0.18	81.09
2	200 feet beyond stopping	3.88	11.71	.75	1.32	.24	82.10
3	600 feet beyond stopping	4.81	9.47	.80	1.78	.20	82.94
4	800 feet beyond stopping	5.33	9.38	1.02	1.13	.48	82.66

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The samples represented in the foregoing tabulations were taken directly from the fire area. Even so, the products of combustion, the carbon monoxide and hydrogen, are comparatively small. This is undoubtedly due to the fact that the temperature was scarcely high enough either for destructive distillation of the coal or for reduction of carbon dioxide by the hot carbon of the coal. The mine itself is a drift mine with a comparatively thin cover and is considered to be normally nongaseous; hence there did not accumulate enough methane to produce an explosive mixture. Neither would the sum total of all three combustible gases scarcely produce an explosive mixture even if enough oxygen was present to produce one. The data given on page 13 of this report indicate that when 3.65 per cent of methane was present there was required 4.98 per cent of carbon monoxide to produce an explosive mixture. This theoretical mixture can be compared to the composition of sample 1, as given on page 27. The sample contained 3.60 per cent of methane, also 2.34 per cent of hydrogen and carbon monoxide a mixture that is not explosive. It will also be observed that the oxygen content was low, owing to absorption of the oxygen by the coal and by the fire, so that an explosion could not have followed even if an explosive proportion of combustible gases had been present.

SAMPLES FROM FIRE AREA OF BITUMINOUS MINE.

The table following gives the composition of samples taken from behind a stopping erected to seal a fire in a bituminous coal mine in Pennsylvania. The samples were collected four days after the sealing of the fire.

Results of analyses of samples of gas from sealed area in a burning bituminous coal mine.

Sample No.	Date of sampling.	Time of sampling.	Constituents in gas.				
			CO_2.	O_2.	CO.	CH_4.	N_2.
	1911.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Nov. 20	1.30 p. m.	4.8	1.6	0.6	(a)	.....
2	....do....	4.30 p. m.	4.8	1.6	.6	(a)	.....
3	Nov. 21	7.45 a. m.	5.87	1.43	1.42	22.27	69.01
4	Nov. 22	11.45 a. m.	5.84	1.02	1.03	24.45	67.66
5	Nov. 23	3.20 p. m.	5.61	1.22	.....	26.18	.....
6	Nov. 27	9.05 a. m.	5.22	.97	1.17	30.86	61.72

The mine wherein the above samples were collected is highly gaseous, the high percentage of methane in the samples being due to the normal accumulation of methane in the mine and not to the fire. A little carbon monoxide was found behind the seal. The proportion actually in the atmosphere at the fire area was, of course, greater than that present behind the seal. The absence of appreciable proportions of hydrogen is again noticeable.

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RÉSUMÉ.

Although the methane that makes a mine gaseous is largely responsible for explosions that take place when ventilation is stopped during a mine fire, in the fire mentioned the inflammable gases—carbon monoxide, methane, and hydrogen—produced by the fire itself were largely responsible.

Methane is the most dangerous gas as regards low limit of explosibility, whereas carbon monoxide and hydrogen are especially dangerous because of their wide explosive ranges.

Heat reactions between coal and air may be studied by comparing mine-fire combustion processes with those in gas producers, gas retorts, and boiler furnaces.

In the destructive distillation of coal large amounts of hydrogen, carbon monoxide, and the paraffin hydrocarbons (principally methane) are formed. At temperatures between 339° and 1,100° C. the proportions may vary—for methane, between 2.50 and 71 per cent; for carbon monoxide, between 2.0 and 16.0 per cent; and for hydrogen, between 0 and 73.0 per cent. At low temperatures the proportions of hydrogen and carbon monoxide formed are lower than the proportion of methane, hence in low-temperature distillation in mine fires the principal danger is from methane. As regards a mine fire that has been burning for some time, it is probable that when the oxygen of the air has been so depleted that products of destructive distillation appear the embers will have cooled to a point where the low-temperature products are given off in largest quantity.

Carbon monoxide formed by the reducing action of hot carbon on carbon dioxide is a highly important agent in some mine-fire explosions.

It is probable that water gas (carbon monoxide and hydrogen), produced by the action of steam on hot carbon, plays a relatively unimportant rôle in causing mine-fire explosions.

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PUBLICATIONS ON MINE FIRES AND EXPLOSIONS.

Limited editions of the following Bureau of Mines publications are temporarily available for free distribution. Requests for all publications can not be granted, and applicants should select only those publications that are of especial interest to them. All requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 68. Electric switches for use in gaseous mines, by H. H. Clark and R. W. Crocker. 1913. 40 pp., 6 pls.

BULLETIN 69. Coal-mine accidents in the United States and foreign countries, compiled by F. W. Horton. 1913. 102 pp., 3 pls., 40 figs.

BULLETIN 72. Occurrence of explosive gases in coal mines, by N. H. Darton. 1915. 248 pp., 7 pls., 33 figs.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 29. Training with mine-rescue breathing apparatus, by J. W. Paul. 1912. 16 pp.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 2 figs.

TECHNICAL PAPER 43. The effect of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

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TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 75. Permissible electric lamps for miners, by H. H. Clark. 1914. 21 pp., 3 figs.

TECHNICAL PAPER 77. Report of the Committee on Resuscitation from Mine Gases, by W. B. Cannon, George W. Crile, Joseph Erlanger, Yandell Henderson, and S. T. Meltzer. 1914. 36 pp., 4 figs.

MINERS' CIRCULAR 7. Use and misuse of explosives in coal mining, by J. J Rutledge. 1914. 51 pp., 8 figs.

MINERS' CIRCULAR 8. First-aid instructions for miners, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 67 pp., 51 figs.

MINERS' CIRCULAR 12. Use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

MINERS' CIRCULAR 13. Safety in tunneling, by D. W. Brunton and J. A. Davis. 1913. 19 pp.

MINERS' CIRCULAR 14. Gases found in coal mines, by G. A. Burrell and F. M. Seibert. 1914. 23 pp.

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MINERS' CIRCULAR 21. What a miner can do to prevent explosions of gas and coal dust, by G. S. Rice. 1915. 24 pp.

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